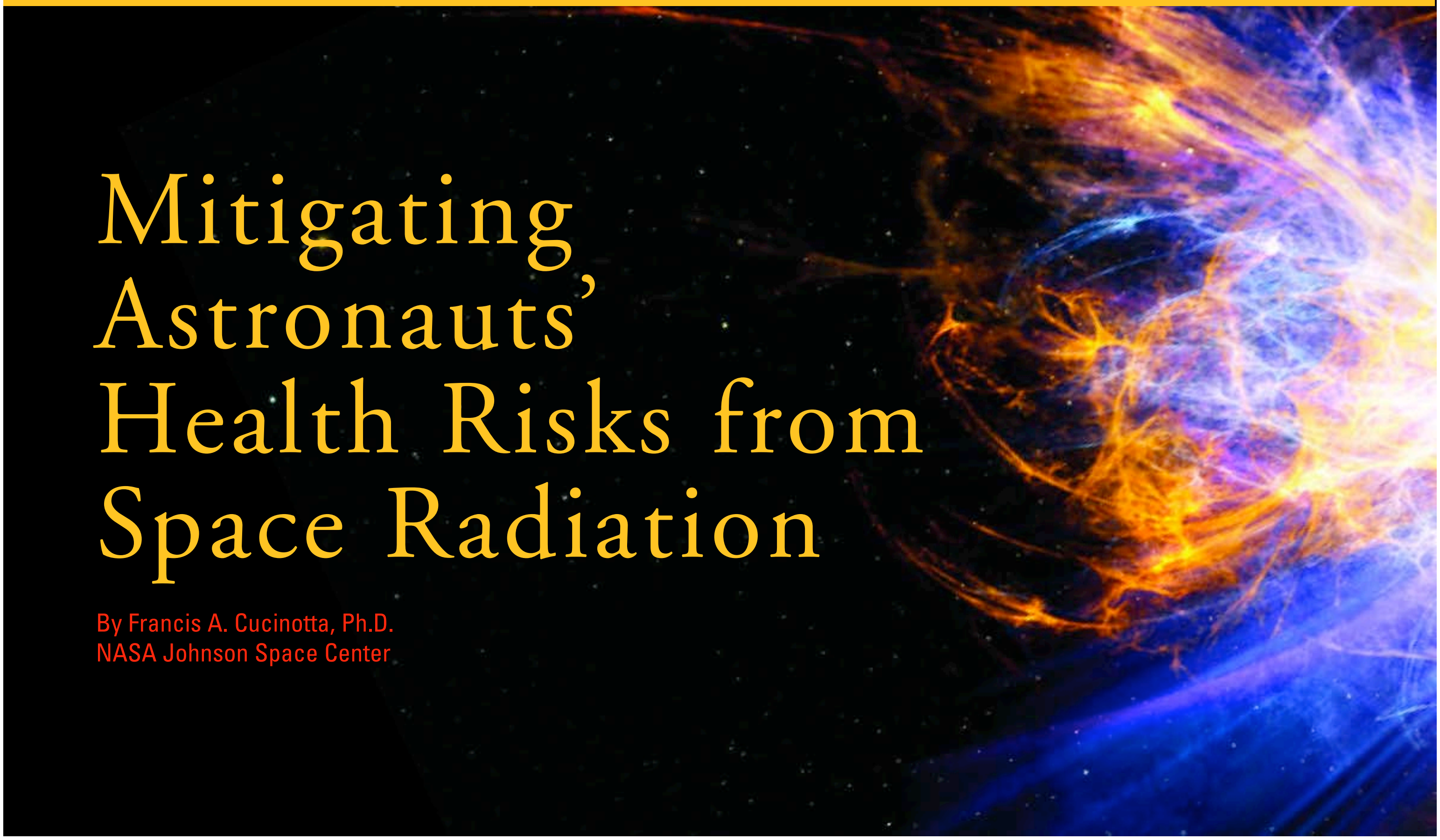


Mitigating Astronauts' Health Risks from Space Radiation

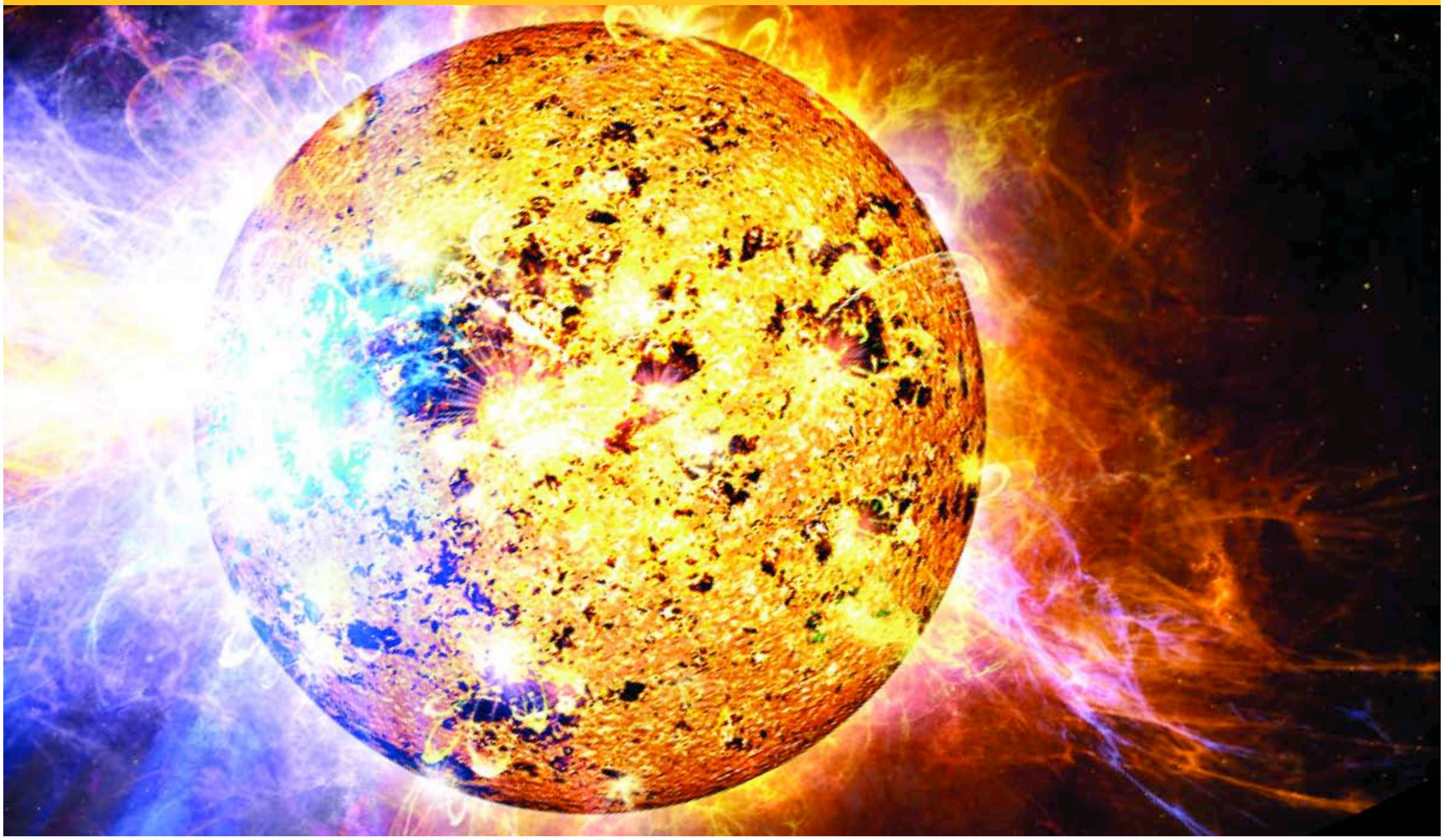
By Francis A. Cucinotta, Ph.D.
NASA Johnson Space Center

One of the unique challenges for NASA is how to protect astronauts from the radiation environment in space. For instance, our sun emits medium- to high-energy protons in what are known as solar storms. The storms vary in size and arise with little warning, and they could expose crewmembers to high doses of radiation when shielding is not present. Also, the stars in our galaxy emit ions that are accelerated by supernova to create highly energetic ions that can burrow deeply into spacecraft structures and tissues.

These resulting galactic cosmic rays (GCR), consisting of high-energy protons and heavy ions such as the nuclei of oxygen, silicon and iron atoms, are the most challenging part of the space radiation problem. This is because their higher energies make them much more penetrating then protons emitted during solar storms, and prohibitive to shield against because of the enormous mass required even for the best shielding material. More importantly, the biological effects of the GCR are poorly understood with uncertainties in current risk projections prohibitive to NASA's exploration plans.

Life on Earth is protected from space radiation by the Earth's atmosphere and magnetosphere, and astronauts in low Earth orbit (LEO) are partially protected with a dose-rate of about 1/3 of that in deep space. As missions outside LEO are planed, the full burden of daily GCR exposures is unavoidable. NASA must find a solution to this problem in order to implement plans for planetary exploration.

The basic understanding of space environments and radiation transport shielding materials was investigated by NASA's Johnson Space Center and Langley Research Center in the 1980's and 1990's. The physical characterization of shielding materials and organ doses is now well understood. Other efforts by Johnson Space Center, with the support of NASA Ames Research Center, have developed radiation dosimetry for real-time characterization of the dynamic space environment. However, a large scientific challenge remains in understanding the radiation biology of health risks such as cancer, and degenerative diseases such as arteriosclerosis, cataracts and



Alzheimer's disease that may be increased or advanced to earlier ages by radiation exposure. This understanding is needed for accurate risk assessments related to setting exposure limits and shielding requirements, and for the development of biological countermeasures.

Partnership with DoE

In order to overcome this challenge, NASA has created a unique partnership with the Department of Energy's (DoE) Brookhaven National Laboratory (BNL) (http://www.bnl.gov/world/) in Upton, N.Y. (Long Island) through the 2003 creation of the NASA Space Radiation Laboratory (NSRL) (http://spaceradiation.usra.edu). Managed by Johnson Space Center, the NSRL utilizes the BNL's large complex of particle accelerator facilities to speed ions to the high energies that occur in space, thus allowing for detailed and controlled experimentation. Along with the capability to accelerate individual ion species from protons to iron that comprise the GCR, the NSRL allows space scientists to investigate mixed radiation fields such as the distribution of energies that occur in the great solar storms, or mixtures of ion types and energies that represent the GCR in deep space or on the Mars surface.

State-of-the art biological laboratories were created at Brookhaven to support the NSRL research program. More than 100 scientists per year from U.S. universities or government laboratories, as supported by NASA through openly competed research grants, will journey to Brookhaven several times each year to irradiate biological samples such as 2D or 3D human cell culture or transgenic mouse models of human disease. The laboratories allow investigators to utilize similar measurement devices for gene and protein expression, confocal microscopy or tissue pathology that they enjoy in their home institutions. They also have the ability to set up their experimental systems or to fix samples prior to transferring them back to their home institutions for further investigation.

This partnership between NASA and DoE allows a smooth operation in the selection of ion beams and energies, the scheduling of scientists to

CREDIT: BROOKHAVEN LAB

THE NASA SPACE RADIATION LABORATORY (NSRL) OPENED IN 2003 AT THE DEPARTMENT OF ENERGY'S BROOKHAVEN LAB TO STUDY THE POSSIBLE RISKS TO HUMANS WHO ARE EXPOSED TO SPACE RADIATION. SHOWN HERE IS THE NSRL BEAM LINE, WHERE BEAMS SIMULATING THE COSMIC RAYS FOUND IN SPACE HELP RESEARCHERS STUDY THESE RADIOBIOLOGICAL EFFECTS.

optimize 12-hour days of exposure with protons and heavy ions, and travel between holding laboratories at the NSRL and long-term laboratories sponsored by NASA in BNL's medical department. NASA and DoE also partner on joint selection of research proposals from the DoE's Low Dose research program. This collaboration increases the scientific pool utilizing NSRL and an annual Space Radiation Summer School at BNL with a goal of attracting the best students to a career in space radiation research.

The Scientific Challenge

On Earth, we are familiar with X-rays and gamma-rays used in medical treatment or diagnostics, or epidemiology studies of experiences of the atomic-bomb survivors in the Japanese cities of Hiroshima and Nagasaki. Energetic photons such as X-rays and gamma-rays cause biological damage through the ionization effects of electrons that are produced as photons traverse cells or tissues.

Two attributes make the GCR different from X-rays or gamma-rays: First their large ionization power, which increases with the square of the charge of the nucleus (for example 82, 142 and 262 for the nuclei of oxygen, silicon and iron, respectively). Their greater ionization power allows GCR to ionize biomolecules in qualitatively distinct ways from X-rays or gamma-rays, creating new types of DNA damage or patterns of damage in cells and tissue. The second difference is the correlation of the damage along the path of the ion. Gamma-rays will produce a random distribution of ionizations in tissues with a slow exponential decrease in dose with tissue depth. GCR produce a correlated pattern of damage along the ions' trajectory, thereby producing a column of damage cells. These two differences limit the applicability of epidemiology studies of humans exposed on Earth for estimating the risks to astronauts. Instead, a basic science approach is needed to develop risk estimates.

Biological research is often very descriptive. However, to aid NASA, a quantitative approach is needed, such as triplicate experiments with multiple ion beams and mixed radiation fields, in some cases using multiple dose-rates. This obviously is a slow process. Further complicating the matter is the long times after exposure called for in cancer and degenerative risk research, and the limits to how often scientists can journey back to NSRL to repeat, iterate and evolve their experiments. However, after seven years of operations, researchers are publishing papers at a rapid pace, discussing research performed at NSRL. More than 60 peer-reviewed articles appeared in scientific journals in 2009.

The immediate goal of the NSRL research is to reduce the uncertainties in risk projections that are a large safety concern and that inhibit mission planning. Uncertainties are a two-sided coin whereby new knowledge can lead either to higher or lower risks along with uncertainty reduction. On the positive side, research is showing the risks of leukemia from GCR is over-estimated in the current radiation protection model followed by NASA. The model originates from the U.S. National Council on Radiation Protection and Measurements (NCRP), a body chartered by Congress to guide federal agencies on radiation protection. On the negative side are results that suggest the risks of solid cancer may be higher than has been estimated, and the risks of degenerative diseases once thought to be less than likely now appear to be very likely for a Mars mission or other long-term space missions.

Only through continued experimentation with more and more sophisticated biological models of human disease will the true answer to the magnitude of the space radiation risk be solved, and approaches to mitigate the risks identified. Key results to date are

CREDIT: BROOKHAVEN LAB

The NASA Space Radiation Laboratory (NSRL) employs beams of heavy ions extracted from Brookhaven's booster accelerator, the best in America for radiobiology studies. NSRL also features its own beam line dedicated to radiobiology research, as well as state-of-the-art specimen-preparation areas.

allowing NASA to focus critical resources on the health risks with higher magnitudes as the main target for biological countermeasure development and will allow more precise estimates of the benefits of shielding materials and crew attributes such as age and gender.

Space radiation research has far-reaching applications on Earth as well. NASA's approaches to the radiation protection of astronauts has benefited radiation protection policies and practices on Earth including in the medical uses of radiation in areas such as computed tomography (CT) and workers at nuclear reactors in the U.S. Studies of the distinct challenges from space radiation and new approaches to countermeasures are enhancing today's research into cancer and the effects of aging. The research also has impacted the development of new cancer therapies that employ high-energy proton and carbon beams to kill cancer cells while producing less damage in the surrounding normal tissues, representing improvements over X-rays.

The pace of NSRL results is accelerating, leading to a growing enthusiasm that in the new decade this innovative approach using inter-Agency cooperation, one-of-a-kind accelerator technologies, and basic science to understand a major challenge to space exploration will be successful. ■

Francis A. Cucinotta, Ph.D., is chief scientist in the NASA Space Radiation Program at Johnson Space Center

For more information, contact Dr. Cucinotta at francis.a.cucinotta@nasa.gov.

Please mention that you read about it in Technology Innovation.